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The Role of Regulation in the Market Integration of the Power to Biomethane Process

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ABSTRACT

The power system does not have the ability of long-term power storage. Therefore, the power to gas technology can offer a sensible solution for this problem in the context of future intersectional energy systems. This can be of high relevance for Denmark and Germany, two countries that are going through a major energy system transition towards renewable power and gas resources. In this study, we investigate the regulatory costs of the "Power to Biomethane" process, a process combining the classical water electrolysis used for power to gas, with the methanation of biogas. The influence of grid tariffs, taxes and support schemes on the economic feasibility of this technology is evaluated. The study shows that in Germany system contributions make up the major share of the per MWh regulatory costs of biomethane produced using the Power to Biomethane process while in Denmark the regulatory costs are made up of different cost factors. The biogas support scheme in Denmark causes the regulatory net costs in this country to be substantially lower than in Germany.

Power to Gas, Power to Biomethane, Tax, Grid Tariff, Regulation, Support, System contributions, System costs

INTRODUCTION

"Power to Gas (P2G)" is a technology enabling the storage of power in the gas infrastructure. This can offer many benefits to a variable renewable energy (VRE)-based energy system [1]. This technology offers an efficient tool to even the road towards a 100% renewable energy based power system [2]. The suitability of P2G for stabilizing highly volatile power grids and offering a storage solution for the future energy system has been proven in several studies such as [3]–[6].

P2G refers to the process in which water is converted into Hydrogen and Oxygen through electrolysers [2]. The Hydrogen resulting from the electrolysis process can be injected into the existing gas infrastructure either in its initial form, or, after going through the methanation process, as methane. [7].

In the first case, Hydrogen is injected into the gas infrastructure in variable but low volumes. The initial idea behind the implementation of the P2G technology is to operate the plant during hours with low or negative power prices, which indicate an excess in renewable power supply [1].

In the second case, Hydrogen reacts with Carbon Dioxide from raw biogas and produces methane (referred to as biomethane). We refer to this reaction as methanation and the entire process as “Power to Biomethane”. Biomethane has similar characteristics as natural gas, and it can be injected into the gas grid without further constraints [5]. According to Græsted et al. (2017), methanation can be expected to be profitable under current Danish conditions, even during times when the power price is relatively high. For the Power to Biomethane process, it is optimal to methanise most of the time, except when power prices are at their peak. Therefore, the typical operation mode for this case would be as baseload, with the exemption of peak hours [8]. The Power to Biomethane utilization path is the focus of this study.

Most of the Power to Biomethane plants in Europe are currently in their demonstration stage and are not operating commercially, and the current market conditions do not enable plant owners to cover their relatively high investment costs [9]. Another reason for this technology not penetrating the market is according to Skov and Mathiesen (2017) that there is currently no need for the pure P2G technology in the market and potential investors perceive P2G as a future technology [10].

One factor that influences the profitability of Power to Biomethane strongly, is national regulation and policy making [9], [11]–[13]. The regulatory frameworks for the integration of different power to gas technologies is currently at an early stage of assessment and evaluation. The majority of the Power to gas projects facilitated in Europe have hydrogen as their output. Due to the Danish gas infrastructure and biogas support scheme, most of the Danish Power to Gas projects seem to focus more on delivering biomethane to the gas grid [12].

This paper aims to investigate the effect of regulation on the marginal costs of the Power to Biomethane process. For this purpose, we focus on grid tariffs, taxes, subsidies, and other regulatory payments as influencing factors and compare the regulatory net costs for this process in Germany and Denmark.

Technology description

As mentioned earlier, the Power to Biomethane process consists of a large-scale water electrolysis reaction and the methanation of biogas, using hydrogen from the electrolysis. Each of these processes have different technical variations and specifications. This paper looks at the regulation concerning the whole power to biomethane process. Nevertheless, we give a brief overview on the sub-processes of electrolysis and methanation in the following section, in order to affirm the framework technology used for the calculations we applied in this paper.

Electrolysis

The electrolysis reaction is a chemical redox reaction, which enables the production of pure Hydrogen and Oxygen from water using electricity. An electrolyser consists of one negatively charged electrode (cathode), one positively charged electrode (anode), a separator, and an electrolyte. The electrolyte is conductive for ions, but not for electrons. During the electrolysis reaction, the anode is oxidized and the cathode is reduced [14]. There are different technologies for electrolysis based on the material used for the anode and cathode, and the electrolyte [15]. For this paper, we assume an alkaline electrolysis, using an alkaline solution such as potassium hydroxide as an electrolyte and producing surplus heat during the process.

Biogas methanation

Biogas is the gas generated by the anaerobic digestion of organic material in the absence of air. It consists mainly of methane, carbon dioxide, water and other trace elements such as ammonia, hydrogen sulphide, hydrocarbons, etc. [16]. Biogas can be cleaned for e.g. sulphur and then be used locally in industry, at a local CHP or a heat boiler. Pure biogas contains approximately 35% CO_2. If most of this CO_2 is removed and thereby upgraded to biomethane (containing maximum 2% CO_2), the biomethane can be used for transport or send to the natural gas grid [17]. One important feature of anaerobic digestion is that the process has to be continual in order to function optimally, and changes in the yield will only happen slowly over days or weeks. This means that the power to biomethane process should be operating almost constantly during the year.

One of the processes that can upgrade biogas to natural gas quality is the "Sabatier process". The Sabatier process is a combination of a reversed endothermal water-gas shift and an exothermal CO methanation [2]. This reaction offers the possibility to use Hydrogen to upgrade biogas and produce biomethane, which can be injected into the gas grid. . It consumes the CO_2 present in biogas and decreases its CO_2 content. Possible unconverted hydrogen in the final biomethane mix improves the combustion properties of the final product. Additionally, the storage of methane is at least three times less than the storage costs of hydrogen. This way more than 90% of the hydrogen is converted into methane [18]: This study considers the catalytic methanation process as described in [19] with surplus heat production.

Methodology

This study is documental in its nature and aims to demonstrate the differences in the regulation affecting the Power to Biomethane process in Germany and Denmark. The approach we use in this study is inspired by [20]. There, Boscán & Roselund (2017) compared the marginal cost of injecting one MWh biomethane with the marginal cost of injecting one MWh natural gas into the gas grid. In this study, we only quantify and compare the regulatory costs, in order to show how these differences add or decrease the per MWh cost of biomethane produced using the Power to Biomethane process.

We have comprised this study in two main parts. The first part, gives an overview of the regulation affecting the Power to Biomethane process both in Denmark, and in Germany. We limit the scope of this study to only the process, and not the input of the process, such as the substrate used for biogas production. Figure 1 shows the process considered in this study. In the second part of the study, we apply the regulatory framework conditions in a quantitative analysis. In this analysis, we calculate the marginal regulatory cost of one MWh biomethane in Germany and in Denmark.

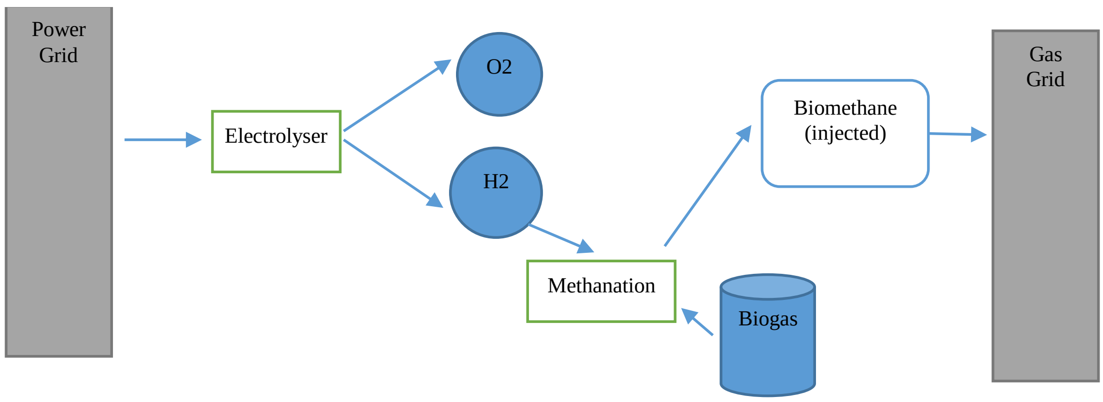

Figure 1: Scope of the paper

In order to show the effect of regulation in the marginal costs of biomethane production from P2G and methanation, we only consider regulation as the variable factor, leaving other framework conditions identical in Germany and Denmark. Typically, the power price is different in Germany and Demark. Denmark has a high wind capacity and is located in the Nordic region next to Norway that is providing the region with a high share of hydropower. Therefore Denmark typically has lower spot prices than Germany, a country with a high share of thermal based power production [21]. However, we assume the wholesale power price and the price of biogas as fixed and equal in both cases in order to clarify the role of regulation.

Both Denmark and Germany have different tariffs for different regional areas and distribution zones. The differences in these costs are not only resulting from the differences in the transmission zones, but also with reference to consumed quantity, duration of use, voltage levels and the possibility of derogation from exceptional and special rules [22]. For the purpose of this study, we take the region of Hamburg in Germany, and the greater Copenhagen Area in Denmark into account. For the technical efficiency and characteristics, we base our assumptions on [19] (see figure 2). Further framework conditions for the calculations are listed in table 1.

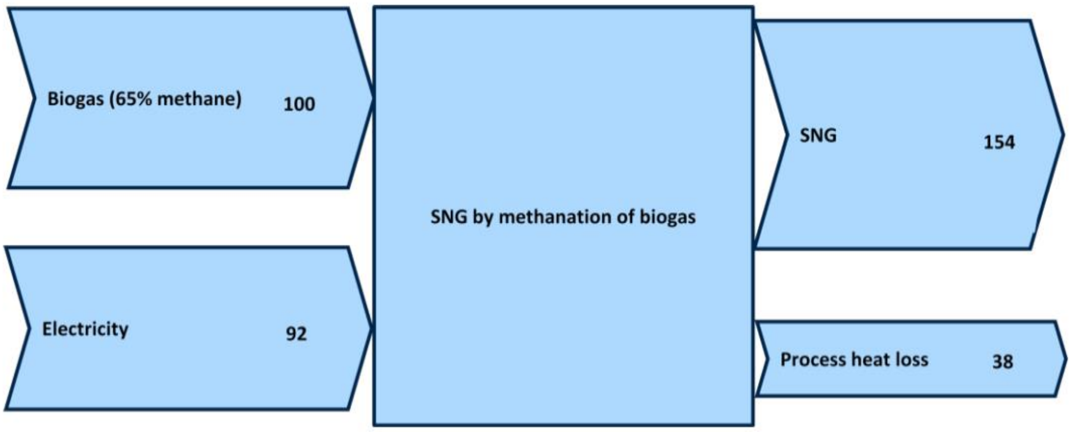

Figure 2: Methanation process estimations according to [22]

Table 1: Fixed framework conditions

Electrolysis process	Alkaline Electrolysis (AEL)
Power to Biomethane efficiency	80,3 %
Plant Capacity	1 MW
Surplus Heat 1	19,7%
Electricity input to Biomethane ratio	0,59
Biogas input to Biomethane ratio	1,54
Power price	0
Production location Germany	Hamburg
Production location Denmark	Copenhagen Area
Annual operation hours	8436

In this paper, we divide the regulatory costs into four main categories: System costs, taxes, system contributions, and support. System costs are the payments that cover the operation and investment costs for the gas and electricity grids and assuring the security of supply. Unless a given technology is granted specific conditions, this is an unavoidable cost and only indirectly determined by the regulator. Taxes are fiscal payments that energy consumers pay to the government. System contributions are payments that are used to develop the overall energy sector further and to support innovations. Support payments are negative costs. They are subsidies that specific technologies and producers receive from the government, in order to incentivize specific products and technology investments.

Denmark

The Danish energy system offers favourable preconditions for the integration of Power to Biomethane. The Danish energy system has a high share of VRE based electricity, where wind energy provides around 45% of the Danish electricity consumption. The Danish gas grid is well developed and contains many storage possibilities, and therefore enables the injection of biomethane [1].

Besides the system related conditions, there are many regulatory drivers for the Power to Biomethane technology, such as tax reductions for process electricity and the subsidies offered to biogas injected into the gas grid. Especially the latter has increased the incentives for biogas plant owners to add their biogas to the energy system as a flexible power and gas production option. In the following sections, we list the regulation affecting the Power to Biomethane technology and investigate which regulatory cost elements are relevant for a Power to Biomethane plant located in the greater Copenhagen area in Denmark.

System costs

The Energy Regulatory Act and the Danish Energy Agency regulate the tariffs in the Danish energy sector. The Danish grid operators are supposed to use grid tariffs to cover their operating, depreciation, financing, and administration costs [23].

The electricity and gas tariffs in Denmark consist of three tariff groups: The transmission network tariffs, the system tariffs, and the distribution tariffs. The transmission network tariffs cover the power transmission grid operation and maintenance costs. The system tariffs cover the cost of security of supply, capacity provision, etc. [24]. Distribution grid tariffs cover the costs of the operation and maintenance of distribution grids. DERA has published methods for the calculation of distribution grid tariffs. However, every distribution grid operator develops its own calculation method, under DERA's supervision. This way, the 60 distribution grid operators in Denmark settle on their individual process for distribution tariffs and conditions.

The bionaturalgas (BNG) entry point is the entry point for biomethane in Denmark. When biomethane is injected into the gas system, the gas shipper (who is transporting the biomethane) will both pay distribution tariffs and transmission tariffs. This is because; the biomethane will have to enter the transmission system – however only virtually, in order to be able to trade the biomethane on the trading platforms and to receive a biogas certificate. The biogas upgrader is obliged to inject the biomethane at a proper gas quality and pressure. If the amount of biomethane exceeds the demand downwards in the distribution system, it is the responsibility of the distribution system, to install a compressor to increase the pressure of the biomethane in order to move the biomethane up in the system. The cost of these tariffs are covered by the end consumer price, with the exemption of the entry capacity the injecting plant needs to buy to assure a space in the gas grid for injection. Table 2 gives an overview over all the tariffs, relevant for the Power to Biomethane technology.

Table 2: Power grid tariffs in Denmark [25]

.Grid costs	**€/MWh**
Transmission grid tariff	7,97
System tariff	3,24*
Distribution tariff	14,43**
Entry capacity BNG	4,74

*[26]
**[27]

Taxes

Power used for electrolysis is levied the minimum EU tax for process purposes in Denmark [28]. Depending on which power to gas technology is used, there might be excess heat produced during the process. The AEL process we consider for our calculations is exothermic and therefore produces heat [29]. For ensuring the ecological feasibility and increasing the efficiency of the Power to Biomethane process, in our calculations the heat produced during the process is recovered.

When companies use energy for a purpose and subsequently recycle the heat produced during the energy conversion process for space heating, water heating or comfort cooling, we refer to the recycled heat as “excess heat”. This dual use of the same energy increases energy efficiency in industrial processes. [28]. Excess heat in Denmark is subject to excess heat taxes [28]. While there are common and wide spread exemptions for excess heat taxes, Power to Biomethane is currently not part of these exemptions [30]. Table 3 shows the taxes affecting the Power to Biomethane process.

Table 3: Taxes applicable to the Power to Biomethane process in Denmark [28]

Tax	**€/MWh**
Electricity tax	0,54
Excess heat taxes	26,75

System contributions

The Public Service Obligation (PSO) is a way to make electricity consumers pay for the development of renewable electricity. Even though the PSO fee is slightly reduced for large customers, it increases total electricity costs significantly; this challenge will however only be temporary, as the PSO gradually will be phased out from 2017 to 2022 [31].

Table 4: PSO tariff in Denmark [25]

Cost group	**€/MWh**
PSO Tariff	23,22

Support

In the Danish energy agreement in 2012, Danish politicians decided to increase renewable energy production, and hereunder biogas. For this purpose, a temporary investment support fund for biogas was established and the conditions under which biogas could receive support was changed together with an increase in the support tariffs. Biogas that is upgraded, used directly for industry, transport or heat and power production can now receive support due to these changes, and this seem to have worked, since biogas production in Denmark have increased significantly since. Several new biogas plants have been built in Denmark the later years and most of these plants upgrade the biogas to biomethane for grid injection [32]. The new biogas support scheme should put upgrading on the same footing as direct consumption in a CHP-plant, so the preference for upgrading may not be directly related to the support scheme. Other reasons could for example be potentially higher biogas prices see e.g. [17] or an access to a higher demand through the gas market and thereby a decrease in production risks while employing the opportunities of economy of scale [32].

The Danish biogas support consists of three price elements: the fixed price settlement, the price supplement 1 and the price supplement 2. The Danish government will phase out of the price supplement 1 until 2020, while the price supplement 2 is gas price dependent. In case of gas price increases, this support will decrease and the other way round in case of gas price decreases [33]. We have listed the different support tariffs for biogas in 2016 in table 5.

Germany

The German regulator perceive P2G plants as end-users [34]. However, the regulation for Power to gas is at an early stage and the German government is planning to update regulation within the next years. The German renewable energy act (EEG) included the definition of storage gas in 2012 as „each gas that is not renewable energy by itself, but is produced for the purpose of storing renewable electricity, only using renewable electricity (§3 EEG 2017). This law only considers a gas to be storage gas, if the end purpose of the gas is electricity production. Due to the high efficiency losses and transport costs of storage gas, this option is usually not economically feasible. Thus, only in the case of re-electrification, the power to gas plant is exempt from additional end-user payments such as the PSO tariff [22].

System costs

Unlike Denmark, Germany has different transmission grid operators for power and gas grids. Therefore, the tariffs and rules for the transmission and distribution of these two commodities show major differences, within the country.

Power

The German national grid agency ("Bundesnetzagentur") is responsible for determining the power grid tariffs in Germany. Besides regional factors, individual grid tariffs are depending on the voltage level in which a company is connected to the grid. The regulation considers a voltage level of 220-380 kV high voltage. The grids within this voltage level are transmission grids. All voltages below this voltage are distribution grids, which are divided in high (110 kV), medium (20 kV) and low (0.2-0.4 kV) voltage levels. However, due to the service P2G plants offer to the grid stability, they are exempt from paying grid tariffs up to 20 years [35].

Gas

The German energy system law perceives hydrogen and biomethane as biogas, if these gases have been extracted from renewable resources (§3 EnWG). The definition of biogas also contains "hydrogen produced via electrolysis and synthetically produced methane, if the power used for the electrolysis and the CO_2 or CO used for methanation is mainly originating from renewable resources".

The German regulator accepts green certificates or a registration of the biomethane injected throughout the utilization path as a proof of that the gas originates from renewable resources [36]. Since biogas is subject to special conditions in the German gas grid, this classification of biomethane is advantageous to Power to Biomethane plants. These plants are exempt from paying gas grid tariffs [37]. The gas grid operator is obligated to attach Power to Biomethane plants with priority to the gas grid, and to guarantee a contractual determined amount of minimum feed in capacity and the availability of the grid connection for at least 96% of the year. Furthermore, 75% of the expenses for the gas grid connection is paid by the grid operator [36].

Table 5: System costs for Power to Biomethane in Germany

Tariff	**€/MWh**
Capacity tariff- gas grid	0
Power grid tariff	0

System contributions

The “EEG Umlage” is the German equivalent of the Danish PSO tariff and we will further refer to it as the PSO tariff. It has been increasing strongly since its introduction in 1998. Rail transport companies and power intensive companies are subject to special exemptions from the payment of the PSO tariff. In case the special conditions for PSO exemption according to the German renewable energy act from 2014 are given, companies are subject to exemptions for their PSO payment [22]. If the P2G plant buys green certificates for the power it uses, the electricity can count as 100% renewable and is exempt from paying the PSO tariff [38]. For power to gas plants, a PSO tariff payment relief can only be relevant, if the gas is fed into the power grid as electricity again [9], [35], [37]. This is not the case for the situation analysed in this article.

There are several other system contributions relevant for German power consumers. Compared to the PSO tariff, these tariffs are insignificant. Table 7 offers an overview on the rate of these tariffs for a Power to Biomethane plant in the Hamburg region.

Table 10: System contributions in Germany [22]

Cost group	**€/MWh**
PSO tariff	68,8
Liability regulation payment for offshore windparks	0,25
Concessionary duty (For special contract customers)	1,1
CHP Tariff	0,3
Interruptible loads payment	0,06
§19 Tariff- Group A (up to 1.000.000 kWh)	3,88

Taxes

The power tax has been introduced in April 1999 during to the ecological tax reform in Germany. Each kWh has the regular tax rate of 20.5 €/MWh. For companies in production the tax rate is 25% less and is currently at 15.37 €/MWh.

There are special industrial processes of producing business entities that are exempt from paying power taxes. Electrolysis is one of these processes [34]. However, it is not clear if power to gas can be subject to this tax exemption, since it may not be perceived as a “producing” company [39]. Recent studies state, that P2G plants can apply for a power tax exemption. The tax authority decides whether to approve these applications [35], [40], [9]. For this reason, we assume the case of a power tax exemption for German Power to Biomethane plants.

Support

The German state supports biogas on the power production stage. The renewable energy act of 2017 includes power from biogas to its introduced auction scheme. Biogas upgrading and the injection of green gases into the gas grid are currently not subject to any direct subsidies.

Results

For our investigation, we summed up the Danish and German regulatory cost elements that we have mentioned in the prior section. Subsidies have been added as negative costs. Since we decided to focus on the differences in regulatory costs, we have set gas and power prices as fixed elements. Thus, these prices are not included as cost and revenue factors here.

Our calculations show that the regulatory costs for biomethane production using the Power to Biomethane process are in the same range in both countries. A major difference between Germany and Denmark is the distribution of costs. While in Germany the PSO makes up a significant share of the regulatory costs, in Denmark tariffs and taxes also play an important role in raising the per MWh cost of the Power to Biomethane process (Figure 3).

The German regulatory cost structure consists of many elements besides the PSO tariff, which have a comparable low significance. The power to gas technology is exempt from paying power taxes and there are no excess heat taxes in Germany. Therefore, there is overall no tax payed for each MWh biomethane produces using Power to Biomethane. In Denmark, excess heat taxes and electricity taxes make up a significant share of the regulatory costs of Power to Biomethane process. However, the subsidy rate payed for the upgrading of biogas is higher than the tax income from the Power to Biomethane plants. For each MWh biomethane, the Danish government pays approximately 30 €.

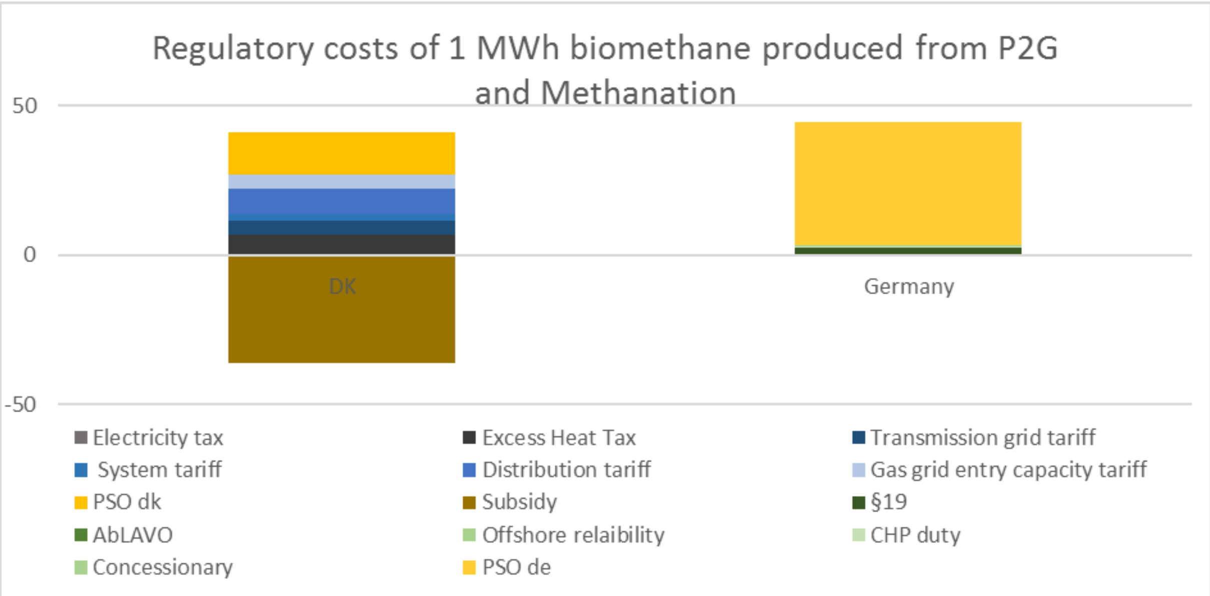

Figure 3: Regulatory costs of 1 MWh biomethane produced from P2G and Methanation

Germany supports biogas only in the case of electrification, whereas Denmark supports biogas also when it is upgraded and injected into the gas grid. The subsidies payed by the Danish state, drive the regulatory costs for the biogas producer down to almost 2 €/MWh. Table 7 and figure 3 show the effect these difference in biogas support cause in the net regulatory cost of biomethane produced by Power to Biomethane.

Table 6: Regulatory costs Denmark and Germany

	Denmark	Germany
Total regulatory costs (€/MWh)	**40,81**	**44,44**
System contributions	13,87	44,43
System costs	20,02	0
Taxes	6,92	0
Subsidies	**-36,12**	**0**
Net regulatory costs (including subsidies) (€/MWh)	**4,69**	**44,44**

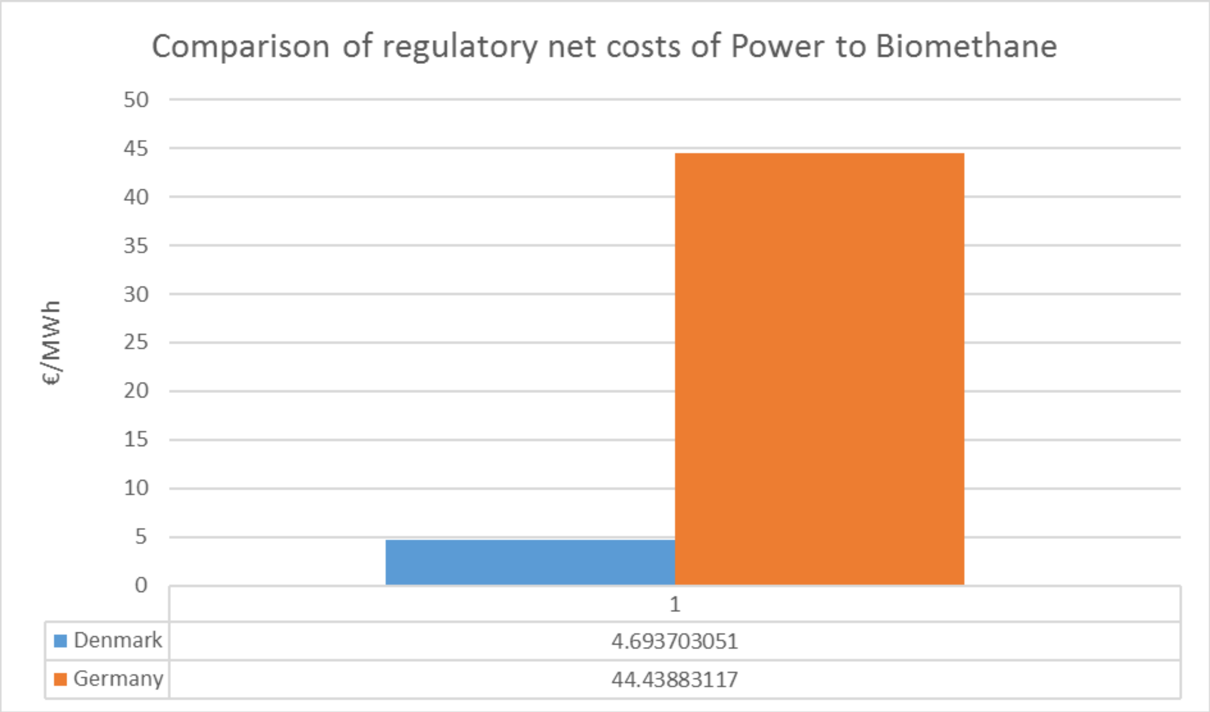

Figure 4: Comparison of regulatory net costs of Power to Biomethane

Conclusion

Neither Denmark, nor Germany have a clear regulatory categorization for Power to Gas technologies. Even though the German legislation contains a category with power storage technologies, power to gas plants would fall into this category only in the case of re-electrification, which is usually the case in electrolysis using solid oxide fuel cells. This utilization path is less efficient than Power to Biomethane and therefore very costly [10].

The German tariff and tax system offers relief for power to gas technologies, regardless of re-electrification. However, the regulatory net costs are higher in Germany than in Denmark. This is due to the categorization of Power to Biomethane as end-consumers and thus, their obligation to pay the PSO tariff. In Germany, the PSO tariff makes up the major share of the production cost of biomethane and is planned to stay an incremental part of the end-user power price, whereas in Denmark the PSO tariff is not as dominant as in Germany and will be phased out within the next years.

The Danish regulator on the other hand, avoids any form of indirect cross-subsidization by offering relief for grid tariffs and taxes. Instead, upgrading biogas is directly subsidised in Denmark, which makes the Power to Biomethane technology more attractive for private investors. The differences in support between Denmark and Germany are the major driver for the big differences in the regulatory net costs of biomethane from electrolysis and methanation in both countries.

In this paper, we did not consider the investment costs for the Power to Biomethane technology. Studies state, that these are the largest part of the cost for this technology and one of the main barriers to its marketability [10], [41]. For this reason, we suggest that regulators take this cost factor also into account, when planning further support for Power to Gas and Power to Biomethane.

References

[1] M. Sterner, M. Thema, F. Eckert, A. Moser, A. Schäfer, and T. Drees, "Stromspeicher in der Energiewende," *Agora Energiewende*, p. 137, 2014.

[2] M. Sterner, *Bioenergy and Renewable Power Methane In Integrated 100% Renewable Energy Systems*. kassel university press GmbH, 2010.

[3] M. Qadrdan, M. Abeysekera, M. Chaudry, J. Wu, and N. Jenkins, "Role of power-to-gas in an integrated gas and electricity system in Great Britain," *Int. J. Hydrogen Energy*, vol. 40, no. 17, pp. 5763–5775, 2015.

[4] A. Belderbos, E. Delarue, and W. D'haeseleer, "Possible role of Power-to-Gas in future energy systems," no. May, pp. 0–4, 2015.

[5] G. Guandalini, S. Campanari, and M. C. Romano, "Power-to-gas plants and gas turbines for improved wind energy dispatchability: Energy and economic assessment," *Appl. Energy*, vol. 147, pp. 117–130, 2015.

[6] S. H. Jensen *et al.*, "Large-scale electricity storage utilizing reversible solid oxide cells combined with underground storage of CO_2 and CH_4," *Energy Environ. Sci.*, vol. 8, pp. 2471–2479, 2015.

[7] M. Sterner and I. Stadler, *Energiespeicher - Bedarf, Technologien, Integration*. Berlin, 2014.

[8] I. G. Jensen, M. Münster, and D. Pisinger, "Optimizing the supply chain of biomass and biogas for a single plant considering mass and energy losses," *Eur. J. Oper. Res.*, vol. 262, no. 2, pp. 744–758, 2017.

[9] F. Graf, M. Götz, M. Henel, T. Schaaf, and R. Tichler, "Technoökonomische Studie von Power-to-Gas-Konzepten Teilprojekte B-D Abschlussbericht," no. November, 2014.

[10] I. R. Skov and B. V. Mathiesen, “Danish roadmap for large-scale implementation of electrolysers,” Copenhagen, 2017.

[11] V. Heinisch, “Modelling the grid integration of power to gas: A case study of Denmark,” 2014.

[12] V. Vartiainen, “Screening of Power to Gas Projects,” 2016.

[13] D. Parra and M. K. Patel, “Corrigendum to ‘Techno-economic implications of the electrolyser technology and size for power-to-gas systems’ [Int J Hydrogen Energy 41 (2016) 3748-3761],” *Int. J. Hydrogen Energy*, vol. 41, no. 6, pp. 3748–3761, 2016.

[14] J. Töpler and J. Lehmann, *Wasserstoff und Brennstoffzelle: Technologien und Marktperspektiven*, 2nd ed. Springer-Verlag, 2017.

[15] M. Goetz *et al.*, “Renewable Power-to-Gas: A technological and economic review,” *Renew. Energy*, vol. 85, pp. 1371–1390, 2016.

[16] E. Ryckebosch, M. Drouillon, and H. Vervaeren, “Techniques for transformation of biogas to biomethane,” *Biomass and Bioenergy*, vol. 35, no. 5, pp. 1633–1645, 2011.

[17] L. Skovsgaard and I. Græsted Jensen, “Why would biogas plants choose to upgrade,” *Not Publ. yet*, 2017.

[18] G. Luo, S. Johansson, K. Boe, L. Xie, Q. Zhou, and I. Angelidaki, “Simultaneous hydrogen utilization and in situ biogas upgrading in an anaerobic reactor,” *Biotechnol. Bioeng.*, vol. 109, no. 4, pp. 1088–1094, 2012.

[19] A. Evald, G. Hu, and M. T. Hansen, “Technology data for advanced bioenergy fuels,” p. 76, 2013.

[20] L. Boscan and E. Rosenlund Soysal, “Framework conditions for flexibility in the Gas – Electricity interface of Nordic and Baltic countries,” 2017.

[21] Danish Energy Regulatory Authority, “National Report,” 2016.

[22] Deutscher Industrie- und Handelskammertag, “Faktenpapier Strompreise in Deutschland,” Berlin, 2017.

[23] DERA, *Danish Electricity Act (lov om elforsyning)*. 2012.

[24] Energinet.dk, “Regulation A : Principles for the electricity market,” *Regulation*, vol. 1, no. December, pp. 1–13, 2007.

[25] Energinet.dk, “Tariffs and Fees,” 2017. [Online]. Available: https://en.energinet.dk/Electricity/Tariffs. [Accessed: 11-Sep-2017].

[26] Energinet.dk, “Aktuelle Tariffer,” 2017. [Online]. Available: http://www.energinet.dk/DA/El/Engrosmarked/Tariffer-og-priser/Sider/Aktuelle-tariffer-og-gebyrer.aspx. [Accessed: 30-Aug-2017].

[27] Radius, “Tariffer og netabonnement,” 2017. [Online]. Available:

http://www.radiuselnet.dk/elkunder/tariffer-afgifter-og-vilkår/tariffer-og-netabonnement. [Accessed: 30-Aug-2017].

[28] PwC, *Samlet overblik over afregning og godt- gørelse af afgifter*. 2016.

[29] Danish Energy Agency, “Technology Data for Energy Plants,” no. October 2013, pp. 1–186, 2016.

[30] Sekretariatet for afgifts- og tilskudsanalysen på energiområdet, “Afgifts- og tilskudsanalysen på energiområdet- Delanalyse 5,” p. Delanalyse 2, 2017.

[31] Energistyrelsen, “FREMSKRIVNING AF PSO -OMKOSTNINGER - OPDATERING AF FREMSKRIVNING FRA NOVEMBER,” 2015.

[32] L. Skovsgaard and H. K. Jacobsen, “Economies of scale in biogas production and the significance of flexible regulation,” *Energy Policy*, vol. 101, pp. 77–89, Feb. 2017.

[33] B. Harder, “Biogas-from a regulators perspective.” 2017.

[34] H. Von bredow and L. Balzer, “Rechtlicher Rahmen für Power-to-Gas : Eine aktuelle Bestandsaufnahme,” no. 10, 2015.

[35] R. Sitte, “Speicher in der Energiewende.”

[36] Fachagentur Nachwachsende Rohstoffe e.V., “Leitfaden Biogasaufbereitung und -Einspeisung,” 2014.

[37] B. Hennig, “Sonderregelungen Power to Gas,” 2017. [Online]. Available: https://www.speicher-bar.de/recht-und-politik/rechtliche-rahmenbedingungen/sonderregelungen-fuer-power-to-gas/. [Accessed: 11-Aug-2017].

[38] Bundesministerium fuer Wirtschaft und Energie, “Erneuerbare-Energien-Gesetz - EEG 2017,” no. 1, 2017.

[39] Energie Innovativ, “Handlungsempfehlung „Power-to-Gas“,” Munich, 3, 2013.

[40] P. Röttgen, “Innovation Power-to-Gas : Stand , Potenziale und Anforderungen für technologieoffene Rahmenbedingungen,” 2014.

[41] E. Tsupari, J. Kaerki, and E. Vakkilainen, “Economic feasibility of power-to-gas integrated with biomass fired CHP plant,” *J. Energy Storage*, vol. 5, pp. 62–69, 2016.